Low-Impurity, Electrode-less, Plasma Source for Fusion Applications

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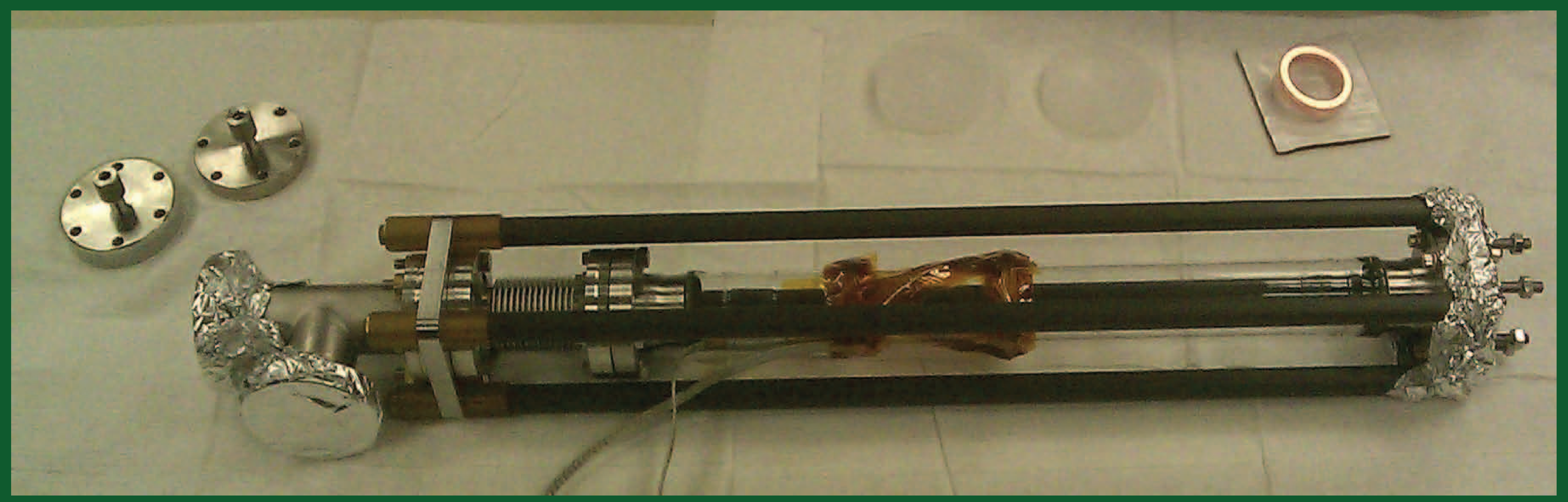
EAGLE HARBOR TECHNOLOGIES

Abstract:

Eagle Harbor Technologies, in collaboration with the University of Washington, has developed a low-impurity, electrode-less plasma source (EPS) for start-up and source plasma injection for fusion science applications. In order to not interfere with the experiment, a pre-ionizer/plasma source must meet a few critical criteria including low impurity production, low electromagnetic interference (EMI), and minimal disruption to the magnetic geometry of the experiment. Two versions of the EPS have been created: a high particle flux device and a low magnetic flux device. Both versions were designed to be bakable and UHV compatable. Here we show the results from the Phase I program, including device construction and integration, plasma properties, and preliminary impurity studies. In addition, we discuss the Phase II work plan, which includes more extensive impurity studies.

EPS Vacuum Hardware:

The first step of this project was to work with HIT-SI researchers to determine the critical design components for a pre-ionizer. This included a discussion of acceptable materials and design practices to meet their ultra-high vacuum (UHV) requirements. Care was given to the selection of materials that would have plasma contact so as to reduce plasma impurities. The result was an EPS made from quartz, stainless steel, and molybdenum and could be bolted to an available 2-3/4" CF flange on HIT-SI. A half-turn, left handed antenna was wrapped around the quartz tube.

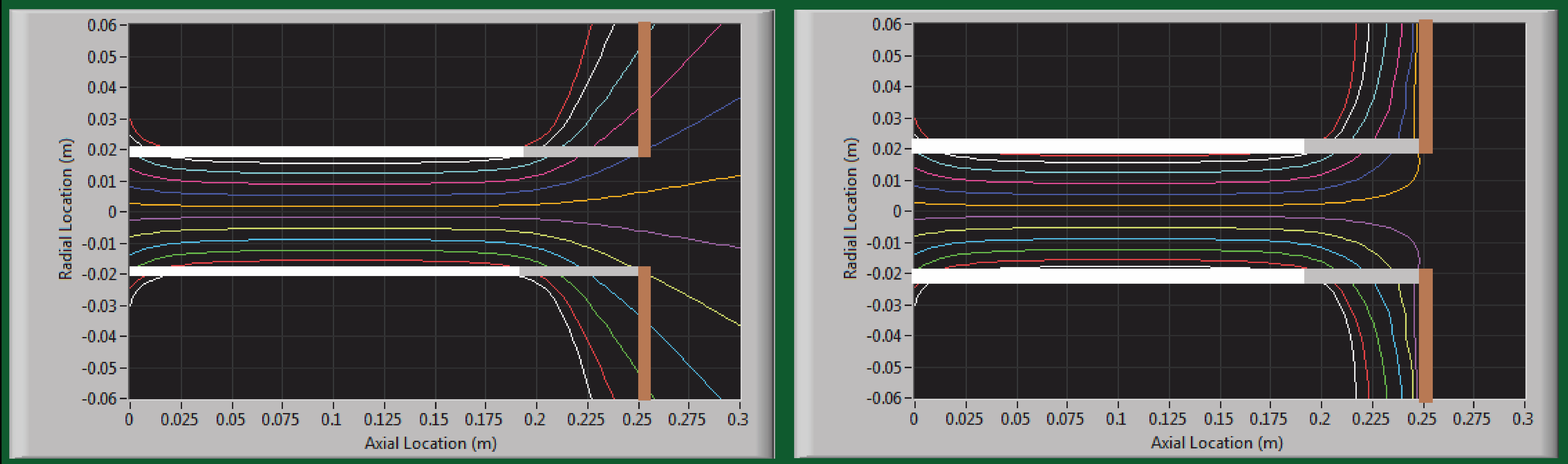


EPS on the bench before installation on the UW test chamber.

Magnetics:

A base magnetic field provided confinement to keep the plasma off the quartz wall and improved the discharge quality. The EPS was typically operated with a solenoid (40 turns) that was capable of producing magnetic fields up to 2 kG, with 300 G for typical operation. Several other magnetic field configurations were quickly investigated and will be studied further in Phase II.

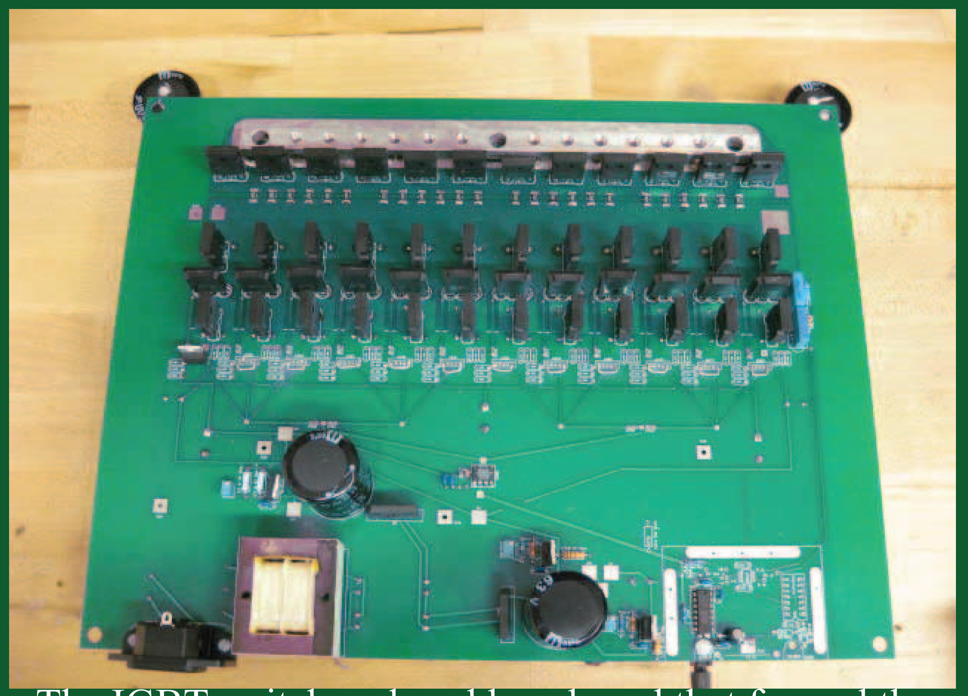
A key technical objective was to demonstrate plasma flow into the main chamber without the base magnetic field penetrating This was accomplished by placing a thick flux-excluding copper flange (10 ms flux penetration time) on the end of the EPS during testing so that the EPS's magnetic field could not extend into the main chamber. The field lines plots are shown below.



Magnetic field lines during DC (Left) and pulsed operation (Right) . White, gray, and tan lines show the approximate vacuum boundaries of various flanges/materials. In both the cases a significant amount of field came into contact with the walls, substantially reducingthe maximum amount of plasma that could be injected into the main chamber.

EPS Power Supply:

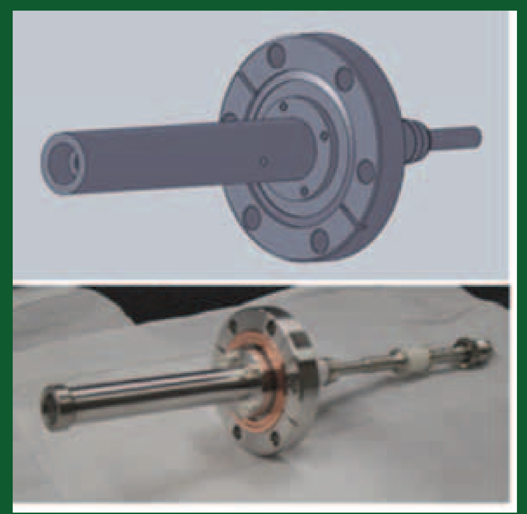
The antenna power supply leveraged work done under a DOE SBIR Phase I and II program *A Robust Modular IGBT Power Supply for Innovative Confinement Concepts* (Poster UP9.00094). The board can switch 1 kA at 1 kV, at frequencies from 100 kHz up to 2 MHz. It contained around $1000 of parts. Board components, specifically the snubbing circuits, were optimized for 600 kHz operation. The IGBT based power supply was connected via a 1:1 transformer to the EPS antenna and a tuning capacitor to form a series resonant network, which was chosen to maximize the power available to the EPS. The circuit had a Q slightly greater than 10.



The IGBT switch and snubbers board that formed the basis of the power supply for the EPS antenna system.

Seed Plasma Generator (SPG):

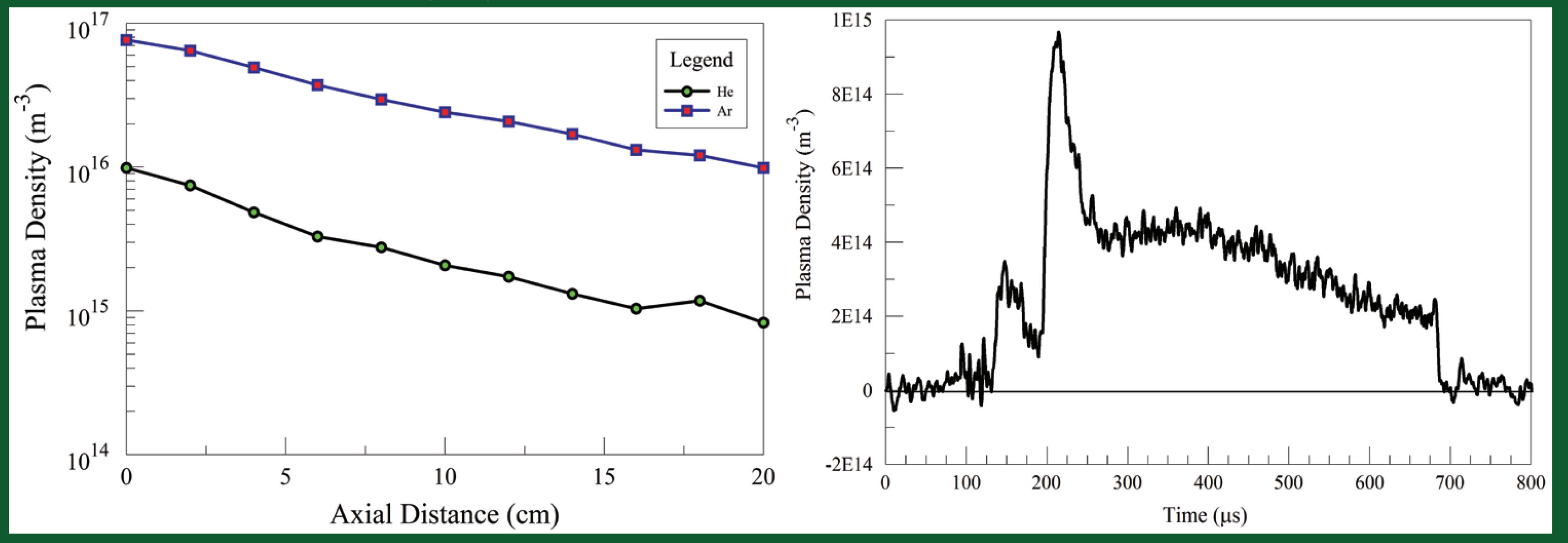
The pre-Phase I system utilized a movable ceramic gas feed. Neutral gas flowed between two charged grids at the end of the feed, generating seed electrons to initiate the inductive discharge with precise timing. However, it was not UHV compatible, thus unsuitable for HIT-SI or other experiments. Further, several of the materials used are not considered good plasma facing surfaces. Thus, the Seed Plasma Generator (SPG) was designed and constructed to be UHV compatable with all of the plasma facing surfaces are steel and molybdenum (grids). The SPG power supply generates -1500 V between the inner and outer grids. The SPG is gated on for 25 µs for a total energy less than 0.5 J. The SPG can be operated with the EPS or as a stand alone system.



SPG: CAD drawing and completed vacuum hardware.

Plasma Density Results:

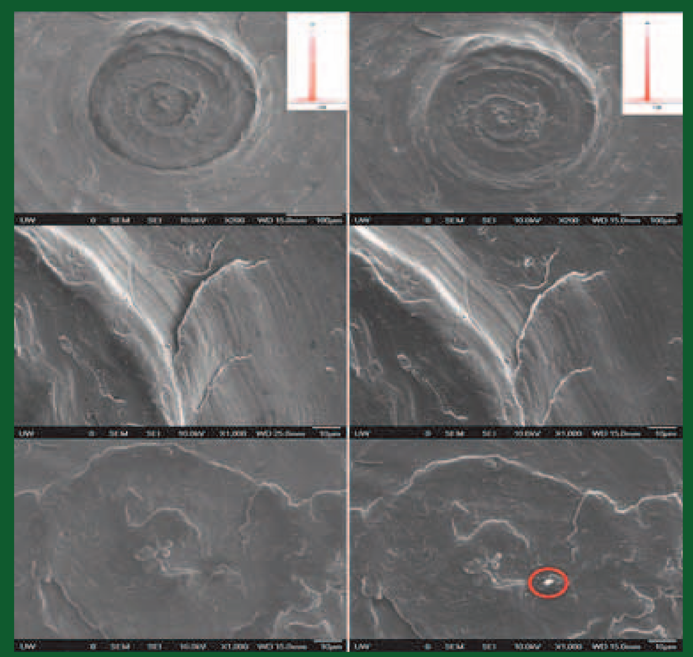
The primary goal was to develop a source to inject plasma into the HIT-SI injectors without injecting magnetic field. The axial fall of in plasma density with distance from the EPS was measured. The figure shows the axial density profile for helium and argon. It was not possible to collect hydrogen data far from the exit due to the smaller probe signal. However, since argon and helium both have the same falloff with distance, hydrogen is expected to have a similar fall off. This data demonstrates plasma injection into the main chamber. In addition, HIT-SI specified that the source should generate plasma for at least one injector cycle (172 µs). The time profile of the density shown in the figure demonstrates that a hydrogen plasma can be sustained for at least 500 µs, which is more than sufficient for HIT-SI. The plasma duration could be increased with additional neutrals being injected.



Left: Helium and argon plasma density in the large vacuum chamber as a function of distance downstream from the EPS. Right: Density temporal profile in hydrogen. The plasma is present for 500 µs.

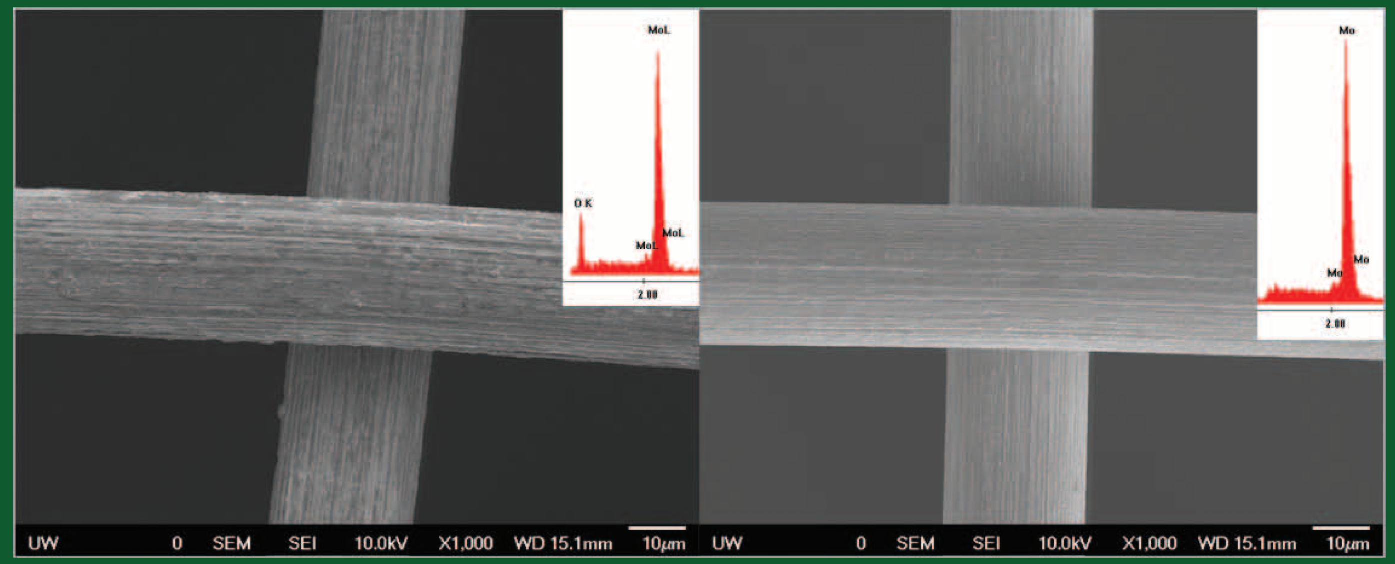
Initial Impurity Study:

An initial characterization of the possible impurity production from the EPS was accomplished using Scanning Electron Microscopy (SEM) to look at an aluminum witness plate placed in at the exit of the device. In addition, Energy Dispersive X-ray Spectroscopy (EDS) was used to investigate potential elemental differences caused by plasma exposure. Before and after plasma interaction SEM and EDS images are shown in the figure, with increasing resolution. A thorough scanning of the witness plate after plasma interaction showed no significant change or impurity capture. Only one small particle approximately 1 µm in diameter was noticed (red circle). EDS analysis of the particle suggest that it is quartz. It may have been generated during the plasma discharge. However, the preliminary results do not suggest significant levels of impurity production.



Left Hand Column: SEM images of Al plate before being inserted into plasma. Right Hand Column: SEM images after 300 hydrogen plasma shots (88 ms total exposure time). The red circle indicates the only impurity that could be located.

In addition, SEM and EDS were used to look at potential grid wear of the SPG. The SPG was operated for 1000 pulses (25 µs each). The figure shows the before and after images of the Mo grid. The only observed effect on the grids was the removal of oxides from the Mo surface. No sputtering damage was seen.

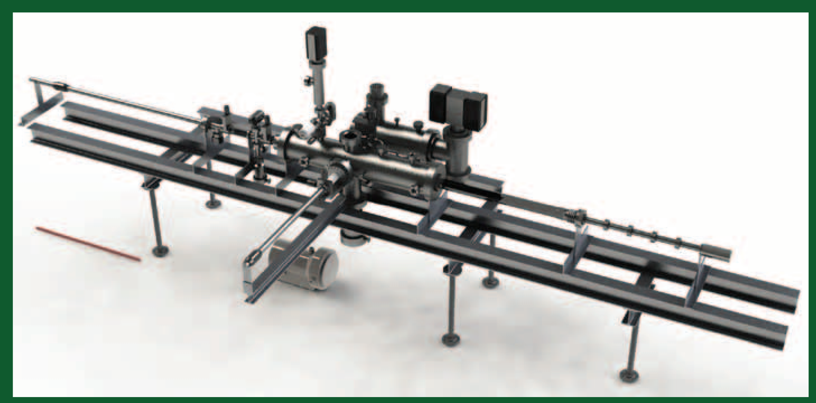


SPG outer molybdenum grid before (Left) and after (Right) 1000 pulses of operation.

Future Work:

During the Phase II program, EHT will take the lessons learned during the Phase I program and design and construct an updated version of the EPS. After verifying the plasma paramters, this device will be installed and tested on HIT-SI. In addition, a higher density/flow rate design will be constructed and validated.

EHT will continue the impurity studies of the EPS. A EPS system has been constructed with an electron excited electron spectroscopy with an in situ sample transfer capability. Additional diagnostics are located at the UW: X-ray excited electron spectroscopy, a 2D mapping high resolution X-ray photoelectron spectroscopy system, Raman spectroscopy, Magic Angle Spinning NMR, and a TEM/Selected-area-diffraction system, as well as both visible and near-infrared photoluminescence microscopy. The EHT system allows for sample transfer under UHV to the UW facilities where required to preserve sample quality.



This work was funded under DOE SBIR/STTR contract number #DE-SC0004480. EHT would like to thank Tom Jarboe and Fumio Ohuchi (University of Washington) and Tian-Sen Huang (Pairie View A&M University) for their letters of support.